Project: Iowa State University, IPF 08-02-1007

Power Fund Award: $2,370,000

Payments Issued to Date: $836,667 (2 payments issued)

Cost Share Invested to Date: $385,435

Project Award Date: November 12, 2008

Project Description:

ISU's proposed research will (1) develop methods for designing clean and efficient burners for low-Btu producer gas and medium-Btu syngas, (2) develop catalysts and flow reactors to produce ethanol from medium-Btu synthesis gas, and (3) upgrade the BECON gasifier system to enable medium-Btu syngas production and greatly enhanced capabilities for detailed gas analysis needed by both (1) and (2). This project addresses core development needs to enable grain ethanol industry reduce its natural gas demand and ultimately transition to cellulosic ethanol production.

(1) The low fuel NOx burner development proposed in this project will play an essential role in enabling the use of a wider variety of biomass without increasing potential to emit when producing the renewable heat and power needed for conventional grain ethanol process. Using biomass for energy improves ethanol's renewable energy ratio to ~4, reduces the cost of ethanol production (which benefits all citizens), and puts energy dollars into the local economy in the form of biomass purchases rather than exporting those energy dollars.

(2) It is quite notable that the theoretical yield of thermochemical ethanol (via gasification) is considerably higher than those of grain ethanol and biological cellulosic ethanol. This means that more renewable ethanol could be produced from biomass derived synthesis gases—potentially enabled by ISU's catalyst research. ISU's proposed research may contribute to reducing our national dependence on foreign oil, reducing the carbon footprint of US transportation, and increasing the prominence of the State of Iowa toward that end.

Update:

(1) Clean burner for biomass-derived producer gas

For the *clean burner development*, we have designed a new burner that features swirling flow motion to enhance fuel-air mixing in order to reduce NOx emissions. Computer simulation of flow and combustion was performed to assess the performance of the proposed burner. A chemical reaction mechanism, consisting of 15 species and 38 reactions, for producer gas combustion and NOx formation was used to simulate the combustion process. Computer simulation results of this swirl burner were compared with those of a baseline burner that is commonly used for natural gas. In the new burner, the premixed producer gas and air entered the burner from different passages. The outside passages were created in a spiral shape to generate swirl to enhance mixing. The computational results indicated that the swirl burner was able to produce more homogeneous combustion, thus reducing combustion temperature and NOx emissions.

Comparisons of the average exhaust temperature and NOx emissions are shown in Table 1. Results indicated that the new swirl burner produced a much lower NOx emissions under the conditions and producer gas composition studied, i.e., equivalence ratio 0.6. We will continue to study the performance of this burner under different operating conditions and also explore various designs.

Table 1 Comparisons of average exhaust gas temperature and NOx emissions for two burners

	Baseline burner	Swirl burner
Average exhaust gas temperature (K)	1,378	1,129
Exhaust NOx emissions (ppm)	418	50.6

On the *upgrade of BECON gasifier*, we have successfully installed a gas conditioning system, baseline gas burner, and combustion chamber at BECON. We are actively working on commissioning this gas conditioning subsystem and anticipate readiness for baseline burner testing by third week of August 2009. Frontline engineers met with ISU faculty and staff and discussed concepts for gas sampling. It is expected that in next quarter Frontline will add a flue gas sample line from the combustion chamber to the existing water knock out station per existing contract. We have also purchased a gas chromatography and a mass spectroscopy for measuring producer gas composition. Additional equipment will be purchased for other required measurements.

(2) Ethanol production through thermochemical processes

For the *syngas-to-ethanol catalyst development*, we have synthesized 2 wt% rhodium (Rh) supported mesoporous silica nanoparticles (MSNs), denoted 2%Rh-MSN, to investigate the optimal loading. In laboratory we used a micro-tubular reactor to screen the catalysts. By employing this micro-tubular reactor, we were able to accelerate the screening process for the optimal catalysts that are suitable for further testing on the fixed bed reactor at a much larger scale. A schematic of the micro-tubular reactor can be found in Figure 1. This is a new reactor and we performed several modifications so we could use our MSN supported catalyst in it. These modifications included getting new packed columns for the gas-inlet gas chromatographer so we can easily separate and resolve both CO and CO_2 peaks when they appear. With this reactor, we have accomplished a few screening runs to examine the catalytic performances of 2%Rh-MSN. We tested this catalyst under different pressure and temperature conditions and used appropriate analyzers to obtain tail gas compositions as well as liquid alcohol contents. We found that the activity of 2%Rh-MSN at

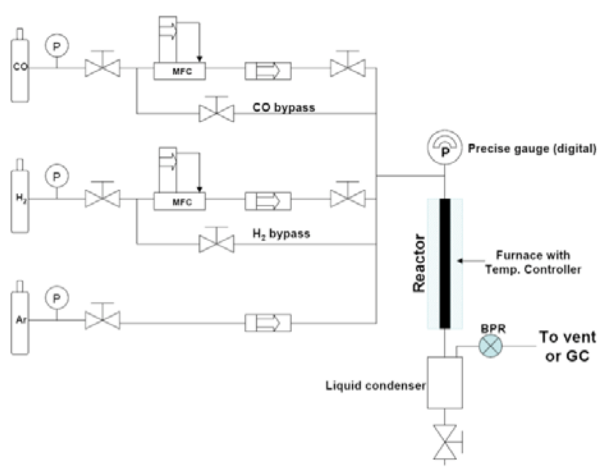

Figure 1 Flow diagram of a micro-tubular reactor

350^{o}C was higher than that at 300^{o}C. However, the selectivity for liquid alcohol products was significantly decreased from 78% to 36.3%, which out-weighted the slightly higher CO conversion at 350^{o}C.

We are currently examining the stability of the 2%Rh-MSN catalyst. We will analyze the selectivity and CO conversion of the reaction over a 60 hour time period and see if the catalyst changes physically or chemically. Once we have the stability determined we will scale up the synthesis of the catalyst so we can test the catalyst using the larger fixed bed reactor system. We will also be completing a more thorough characterization of the catalyst in the near future.

For the *syngas-to-ethanol flow reactor* testing, we have focused on the modification and upgrading of an existing fixed bed reactor that will be used for syngas to ethanol reaction in this project. Significant amount of work has been done and the system is now fully operational. Three new mass flow meters (for H_2, CO and He, respectively) that are capable of controlling small flows have been purchased and installed on the fixed bed reactor. This will make it possible to investigate the syngas to ethanol reaction using lower gas hourly space velocity, which is the favorite reaction for ethanol production as reported.

A new stainless steel 250ml condenser has been designed, fabricated and installed on the fixed reactor system. Previously, liquid sample was collected after back pressure regulator (BPR) at atmospheric pressure. In order to prevent condensation of liquid inside pipeline and regulators, heating tape was used to maintain relatively higher temperature for the reaction products. However, this could damage some parts and sealing of valves and BPR as we observed. It is important to have a condenser installed before BPR so the reliability of system will be ensured.

It was found that there was a temperature gradient for the zone where the catalyst was originally placed. The temperature difference between top and bottom of catalyst bed was so significant that we had to re-examine the reactor heating system and to improve the system so a uniform reaction temperature for catalyst bed could be assured. Having done this work, now the reaction temperature can be controlled precisely and uniformly along the catalyst bed.

In the mean time, we are designing another reactor with smaller size that is capable of screening catalytic material more efficiently. It is hoped that by combinational usage of these two reactors, the process for the development and scaling up of novel catalysts for the syngas to ethanol reaction can be accelerated.

T91466

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			DEC 2008 THRU MAY 2009		
001	43900		PER ABOVE INVOICE	0.00	363,912.80
	CLASS	IRS	FUND-ACCT SC PROJ AMOUNT SURCHARGE		
	439 00		478-17-18 363,912.80 363,912.80		
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ITEM NO	CLASS CODE	QUANTITY INVOICED	DESCRIPTION	UNIT PRICE	EXTENDED AMOUNT
			JULY 2009		
001	43900		PER ABOVE INVOICE	0.00	40,978.20
	CLASS	IRS	FUND-ACCT SC PROJ AMOUNT SURCHARGE		
	439 00		418-17-18 40,978.20 / 40,978.20		
			PLEASE PROVIDE FUND NUMBER		
				TOTAL	40,978.20

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